CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-201
SOUTHERN WHITE MOUNTAINS FAULT ZONE, NORTHERN INYO COUNTY, CALIFORNIA

by

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October 24, 1988

INTRODUCTION

Potentially active faults in northern Inyo County that are evaluated in this Fault Evaluation Report (FER) include faults that comprise the southern White Mountains fault zone (Figure 1). The Waucoba Mtn. study area is located in the western half of the Waucoba Mtn. 15-minute quadrangle (Figure 1). Traces of the White Mountains fault zone just west of the Waucoba Mtn. study area were zoned for Special Studies in 1984 on the NE 1/4 of the Big Pine 15-minute quadrangle (summarized in Hart and others, 1984). Faults were not evaluated to the east of the Big Pine quadrangle at that time. However, new information (dePolo, written communication, August 1988) made available to the Division of Mines and Geology indicates that recently active traces of the White Mountains fault zone extend southeast of the area previously zoned in 1984. Traces of the White Mountains fault zone in the Waucoba Mtn. quadrangle are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1985).

SUMMARY OF AVAILABLE DATA

The Waucoba Mtn. study area is located along the east side of the Owens Valley, a major, north-trending fault-bounded depression situated between the Sierra Nevada to the west and the White-Inyo Mountains to the east (Figure 1). The study area is located in the western part of the Basin and Range geomorphic province and is characterized by oblique Basin and Range extensional tectonics which results in both normal and right-lateral faulting.

Topography in the study area ranges from gently west-sloping alluvial fan surfaces to the relatively rugged west-facing fronts of the southern White Mountains and northern Inyo Mountains. Elevations in the study area range from 1170 meters to over 1600 meters above sea level. Development in the study area is low and is generally limited to agriculural and recreational use. The town of Big Pine is located approximately 3 km west of the study area (Figure 1). Precipitation is low and averages about 15 cm/yr (Bishop airport area).

Rock types in the study area include Paleozoic sedimentary and metamorphic rocks, minor Mesozoic intrusive rocks, Quaternary volcanic rocks, and Quaternary sedimentary deposits (Nelson, 1966; Strand, 1967; Bachman, 1974, 1978). Quaternary sedimentary deposits include Plio-Pleistocene lacustrine deposits of ancient Waucoba Lake, and late Pleistocene and Holocene alluvium (mainly alluvial fans consisting of detritus derived from the White-Inyo Mountains).

The White Mountains fault zone is a major, north to northwest trending zone of normal and right-lateral strike-slip faults extending approximately 115 km along the west front of the White Mountains and the northern Inyo Mountains. The White Mountains fault zone north of the study area was evaluated in FER-153 (Bryant, 1984a), FER-159 (Bryant, 1984b), and FER-161 (Hart, 1984). Traces of the White Mountains fault zone have evidence of Holocene activity, are well-defined, and were recommended for zoning for special studies. Surface fault rupture associated with the July 1986 Chalfant Valley earthquake was mapped along traces of the White Mountains fault zone north of the study area (Kahle and others, 1986; Lienkaemper and others, 1987; dePolo and Ramelli, 1987). Approximately 15 km of discontinuous fault rupture was mapped. Normal right-lateral oblique-slip up to 5 cm was reported (dePolo and Ramelli, 1987; Lienkaemper and others, 1987).

Mapping that will be evaluated in this FER includes Nelson (1966), Bachman (1974), dePolo (written communication, August 1988), and Slemmons and students (1970, not plotted on Figure 2) (Figure 2). The southern White Mountains fault zone in the study area can be divided into three sections for purposes of discussion. The northern section, termed here the Waucoba Embayment section, extends from the northern part of the study area southeast to just south of Waucoba Road (Figures 1 and 2). The central section, termed here the Mule Spring section, extends from the vicinity of Waucoba Road south to the vicinity of locality 5 (Figure 2). The southern section, termed here the Aberdeen Road section, extends south and west from locality 5 to the southern end of the study area (Figure 2).

Traces of the southern White Mountains fault zone mapped by Nelson (1966) are shown in orange on Figure 2. Nelson did not differentiate between Pleistocene and Holocene alluvium, instead grouping all alluvial deposits under the heading of Quaternary. However, Nelson's alluvial units (Qvf, Qa, and Qf) are assumed to be latest Pleistocene and Holocene in age.

The Waucoba Embayment section of the southern White Mountains fault zone mapped by Nelson (1966) is delineated by a broad, northwest-trending zone of complex normal faults delineated by both east and west-facing scarps (Figure 2). Faults mapped by Nelson within this complex zone offset Quaternary alluvial deposits (Plio-Pleistocene Waucobi Lake beds and fanglomerate that in part overlies and interfingers with the lake deposits). Nelson mapped a young alluvial fan (his Qa unit) as offset at locality 1 (Figure 2). The fault is delineated by a west-facing scarp, is very short, and was not mapped to the southeast. Nelson also mapped offset young alluvium (unit Qa) to the north along the range front at Wilkerson and Ulymeyer Springs (locality 2, Figure 2).

The Mule Spring section of the southern White Mountains fault zone mapped by Nelson is located within Paleozoic bedrock and does not offset young alluvial deposits (Figure 2). The west-facing front of the White Mountains is roughly linear, but Nelson did not map faults along the mountain front, except for short, discontinuous faults that are concealed by young alluvium east and northeast of Tinemaha Reservoir (Figure 2).

The Aberdeen Road section of the southern White Mountains fault zone mapped by Nelson is delineated by a west to southwest-trending fault that offsets Nelson's Qoa alluvial unit, but is concealed by young (Holocene) alluvium (Figure 2).

Faults mapped by Bachman (1974) (shown in red on Figure 2 (insert)) are limited to the Waucoba Embayment section of the southern White Mountains fault zone. Both Holocene and Pleistocene alluvial units are mapped by Bachman. Bachman reported that most of the faults he mapped in the study area are high-angle normal and are delineated by both east and westfacing scarps. Predominant movement along the fault zone reported by Bachman is down-to-the-west normal. Bachman did not know the maximum cumulative displacement along the southern White Mountains fault zone. Holocene alluvium is offset at localities 1 and 2 (Figure 2). Faults mapped by Bachman generally correspond with faults mapped by Nelson (1966), although differences exist, particularly in the Graham Ranch area (vicinity of locality 3, Figure 2 (insert)). Faults mapped by Bachman in this area form a very broad and complex zone of both east and west-facing scarps in Pleistocene alluvium. Bachman reported that an approximately 1 meter high scarp at locality 3 (Figure 2) was unusually fresh and he postulated that the scarp may have formed during the 1872 Owens Valley earthquake.

Faults mapped by dePolo (written communication, August 1988) are shown in blue-green on Figure 2. dePolo's map is preliminary (un-completed Master of Science thesis) and the copy obtained by this writer was not annotated and did not have a map explanation. However, dePolo did highlight specific fault traces he believed to exhibit Holocene activity (indicated by a boxed H in blue-green on Figure 2). Not all faults mapped by dePolo have been plotted on Figure 2 (mostly those faults in bedrock east of the Inyo Mountain front were not plotted). Traces of the southern White Mountains fault zone mapped by dePolo loosely correspond with faults mapped by Nelson (1966) and Bachman (1974), although considerable differences in detail exist, especially along the Mule Springs section (Figure 2). dePolo mapped young (Holocene) alluvium offset along the western branch of the Waucoba Embayment section of the southern White Mountains fault zone (locality 1, Figure 2). This fault strand differs in location and extent from faults mapped by Nelson (1966) and Bachman (1974). dePolo did not map faults in the Graham Ranch area with the same complexity as did Bachman (1974) (Figure 2).

dePolo (p.c., August 1988) reported that several areas along the southern White Mountains fault zone in the study area probably ruptured in mid to late Holocene time (localities 1, 4, and 6, Figure 2). A paleoseismic fault rupture event dePolo calls the Black Mountain rupture probably occurred in mid- to late Holocene, based on geomorphic evidence (un-filled depressions, knickpoints in soft alluvial deposits) and fault scarp profile data (Ramelli and dePolo, 1987; dePolo and Ramelli, 1987; dePolo, p.c., August 1988). Possible 1872 rupture may have occurred along discontinuous strands of the southern White Mountains fault zone at locality 4 (Figure 2). dePolo based this conclusion on freshness of scarps (some of the free-face was preserved) and knickpoints in unconsolidated alluvium.

Slemmons and students (1970) incompletely mapped traces of the southern White Mountains fault zone in the study area (not plotted on Figure 2). The available base map on which Slemmons and students was plotted is very poor and more detailed mapping is available from dePolo. Therefore, mapping by Slemmons and students will not be evaluated.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Waucoba Mtn. study area was accomplished using U.S. Bureau of Land Management (1977) (CA01-77, approximate scale 1:24,000) and University of Nevada, Reno (1985a) (WMFZ, approximate scale ranges from 1:12,600 to 1:17,000) aerial photographs.

Approximately 2 days were spent in the field in August 1988 by this writer. Selected fault traces were verified and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized on Figure 3.

Fault scarp heights and scarp-slope angles were measured in order to estimate recency of faulting, based on the work of Wallace (1977). A direct correlation between the ages indicated by fault scarp profiles measured by Wallace (1977) in Nevada and scarp profiles measured during investigations for this FER cannot be made due to different lithology, climate, and style of faulting (Mayer, 1982). However, the data presented by Wallace (1977, 1978) can be used as a guide (or additional factor) when evaluating the geomorphic features and age of offset deposits (when known) for recency of faulting. Some very general guidelines for estimating scarp ages are summarized as follows. Fault scarp angles for faults in unconsolidated alluvium and colluvium no older than 10,000 to 12,000 yrs BP can range from 10o to 35o (Wallace, 1977). The average scarp angle is about 22o, based on Figure 8 of Wallace (1977), although Figure 12 of Wallace (1977) indicates that scarp angles of about 19o represent minimum Holocene age. The scarp crest width for scarps no older than about 10,000 yrs BP ranges from 1 to about 6 meters (Wallace, 1977, Figure 11). Wide variations occur, but these figures probably represent minimum criteria suggesting Holocene ages.

In addition, fault scarp profiles were measured across selected fault strands in order to calculate the morphologic age of the scarps using the computer program of Nash (1986, 1987). In order to determine the morphological age of a scarp (t=time of degradation of original configuration of scarp), it is necessary to determine the rate of erosional degradation, the diffusivity constant c. In the Waucoba Mtn. study area the value for c is unknown. However, studies by Hanks and Wallace (1986) have determined that the value for c ($0.001m2/yr$) seems to be consistent throughout the Great Basin. Therefore, $c=0.001m2/yr$ will be used for morphologic age calculations in this FER. However, values for t derived in this FER should be considered to be preliminary.

Traces of the southern White Mountains fault zone in the study area are generally moderately well to well-defined in the Waucoba Embayment section, moderately to poorly defined in the Mules Springs section, and locally well-defined in the Aberdeen Road section (Figure 3).

Waucoba Embayment Section

The Waucoba Embayment section of the southern White Mountains fault zone consists of a northwest-trending zone of complex, generally normal faults delineated by both east and west-facing scarps (Figure 3). The style of faulting is very distributive and complex. Most of the faults north of Westgard Pass Road are moderately well to well-defined and are delineated by geomorphic evidence of latest Pleistocene to Holocene normal displacement (Figure 3). A component of right-lateral strike-slip displacement was not observed, based on the geomorphic expression of the fault. However, a very minor component of strike-slip displacement cannot be ruled out.

The fault trace at locality 7 (Figure 3) is well-defined and offsets a relatively thin veneer of Holocene colluvium. This fault, mapped by Nelson (1966), Bachman (1974), and dePolo (written communication) with reasonably good agreement, is delineated by a partly dissected, west-facing scarp (Figure 3). The scarp profile strongly indicates Holocene displacement (locality 7, Figure 3). Additional geomorphic evidence of Holocene displacement along this fault strand includes a closed depression and associated ponded alluvium, vertically offset drainages, and offset Holocene deposits (Figure 3). This fault strand trends northwest out of the study area onto the NE 1/4 of the Big Pine 15-minute quadrangle (Figure 3). The NE 1/4 of the Big Pine quadrangle was evaluated in FER-159 (Bryant, 1984b), but the fault strand in question was inadvertently overlooked. However, this fault is well-defined and has geomorphic evidence of Holocene displacement (locality 7, Figure 3).

The site where dePolo reported a freeface scarp angle of 38° was only partly verified by this writer, based on field inspection (scarp slope angles ranged from 28° to 32°, locality 8, Figure 3). However, a scarp in a terrace deposit was modeled using the degradation model of Nash (1986, 1987) (locality 8, Figure 3; Table 1, profile WM01). The modeled age of the scarp suggests an extremely young fault rupture event, possibly of historic age. This agrees with the conclusions of dePolo, who postulated that this fault may have coseismically ruptured in 1872 (p.c., August 1988).

South of Westgard Pass Road, the Waucoba Embayment branch of the southern White Mountains fault zone becomes very broad and distributive in a zone up to 4 km wide (Figure 3). Faults generally are less well-defined and geomorphic evidence of Holocene faulting is much less abundant than north of the road. These faults mostly offset Plio-Pleistocene deposits and only locally offset Holocene deposits (Figure 3).

One notable exception is at locality 1 (Figure 3) where Holocene alluvium is offset. A well-defined, west-facing scarp in Holocene alluvium has a scarp profile that further indicates Holocene displacement (locality 1, Figure 3). This fault trace can be extended farther south than mapped by Bachman (1974) and Nelson (1966) and differs somewhat in location (Figures 2 and 3). dePolo extended this fault trace farther south than this writer could verify and dePolo's location appears to be located too far to the east.

Faults mapped by Bachman (1974) in the Graham Ranch area generally are not well-defined and were not verified by this writer. Air photo interpretation by this writer of the area near Graham Ranch where Bachman reported a fresh scarp (1872?) indicates that almost all of the youthful scarps and grabens present are probably the result of, or have been enhanced by landsliding. dePolo (p.c., August 1988) verified that most of these fresh scarps are probably the result of landsliding. However, dePolo was not able to precisely locate the scarp reported by Bachman.

Mule Spring Section

The Mule Spring section of the southern White Mountains fault zone generally is poorly defined and/or lacks geomorphic evidence of recent faulting (Figure 3). The north-trending fault mapped by dePolo along the west-facing front of the White Mountains is poorly defined and lacks geomorphic evidence of latest Pleistocene to Holocene displacement. Holocene alluvial fans are not displaced and, except for vague tonal lineaments just northeast of Tinemaha Reservoir (locality 9, Figure 3), there is no geomorphic evidence of recent faulting.

A linear northwest-trending fault zone in bedrock mapped by both Nelson (1966) and dePolo was partly verified by this writer (locality 10, Figure 3). However, this fault strand is only moderately defined and is delineated by geomorphic features more characteristic of erosion along a fault rather than latest Pleistocene to Holocene fault rupture. Southeast of sec 31, T9S, R34E the fault mapped by dePolo is characteristic of a moderately west-dipping fault (Figure 2). This branch fault is poorly defined and was not verified by this writer.

Aberdeen Road Section

The Aberdeen Road section of the southern White Mountains fault zone is delineated by fault strands that are moderately well to well-defined and are delineated by geomorphic evidence of latest Pleistocene and Holocene normal displacement (localities 11, 12, and 13, Figure 3).

Faults mapped by dePolo (written communication, August 1988) along the Aberdeen Road section generally were verified by this writer (Figures 2 and 3). There is moderately good agreement in location between Nelson (1966), dePolo and this writer with respect to the east-trending fault at locality 12 (Figure 3). This fault offsets Pleistocene alluvium (late Pleistocene?) and is delineated by a well-defined north-facing scarp (locality 12, Figure 3). The scarp profile suggests latest Pleistocene to Holocene activity (scarp h=7.6m; $<=20^{o}$; crest=2 1/2 m). The fault changes trend almost 90^{o} to the north, forming a tight right-stepping pattern within the bend area (locality 12 , Figure 3). The north-trending fault strand is well-defined and offsets Holocene alluvial fans. Scarp profiles also indicate Holocene displacement (e.g. locality 11, Figure 3).

The southern extent of the Aberdeen Road section extends south onto the Independence 15-minute quadrangle (Blackrock 7.5-minute quadrangle) (Figure 3). The fault locally is well-defined and offsets Holocene alluvium. This southern part of the fault was not mapped by Nelson, but mapping by dePolo was verified by this writer. The fault scarp profile at locality 13 (Figure 3; Table 1, profile WM02) suggests a late Holocene age of faulting. This part of the Aberdeen Road section of the southern White Mountain fault zone was previously evaluated and recommended for zoning in FER-192 (Bryant, 1988).

SEISMICITY

Seismicity in the Waucoba Mtn. study area is depicted in Figure 4. A and B quality epicenter locations by California Institute of Technology (1985) and University of Nevada, Reno (1985b) are for the period 1932 to 1985.

The Waucoba Mtn. study area is characterized by a moderate level of seismicity that may be associated with the southern White Mountains fault zone, although most of the seismicity is located northwest of the study area (Figure 4). Three events associated with the Waucoba Embayment section are located between Westgard Pass Road and Waucoba Road (Figure 4). A Magnitude 4.0 - 4.9 event is located about 3 km east of the Mule Spring section and may not be associated with mapped traces of the southern White Mountains fault zone. Distinctive patterns of seismicity that can be directly related to specific fault traces are not present (Figure 4).

CONCLUSIONS

The southern White Mountains fault zone is a moderately defined to well-defined, north to northwest-trending zone of complex, locally distributive normal faults (Figures 2 and 3). The White Mountains fault zone north of the Waucoba Mtn. study area is well-defined, has evidence of Holocene displacement and is zoned for Special Studies (Bryant, 1984a, 1984b; Hart and others, 1984).

Waucoba Embayment Section

The Waucoba Embayment section of the southern White Mountains fault zone in the Waucoba Mtn. study area is moderately to well-defined and locally has evidence of Holocene normal displacement and possible historic fault rupture, based on geomorphic evidence such as un-filled closed depressions, knickpoints in unconsolidated alluvium, and youthful scarps in unconsolidated late Pleistocene and Holocene alluvium (dePolo, p.c., August, 1988; localities 1, 4, 6, 7, and 8, Figures 2 and 3).

Faults mapped by Nelson (1966), Bachman (1974), and dePolo (written communication, August 1988) were locally verified by this writer, although significant differences in detail exist (Figures 2 and 3). Faults mapped by Bachman (1974) in the Graham Ranch area generally are poorly defined and were not verified by this writer (locality 3, Figure 2). Well-defined scarps and grabens in the Graham Ranch area probably formed or were enhanced by landsliding, possibly associated with the 1872 earthquake. Faults mapped by dePolo were locally verified by this writer, although many of dePolo's traces are Quaternary active but are not delineated by geomorphic evidence of latest Pleistocene to Holocene activity (Figures 2 and 3). A well-defined fault strand can be mapped northwest of the Waucoba Mtn. study area onto the Big Pine 15-minute quadrangle (locality 7, Figure 3). Although the NE 1/4 of the Big Pine quadrangle was evaluated in FER-159 (Bryant, 1984b), the fault strand at locality 7 was inadvertently overlooked.

Mule Spring Section

The Mule Spring section of the southern White Mountains fault zone is generally poorly defined and does not have geomorphic evidence of latest Pleistocene to Holocene displacement (Figures 2 and 3). Faults mapped by Nelson (1966) and dePolo (written communication, August 1988) were not verified as latest Pleistocene to Holocene active by this writer, except at locality 9 (Figure 3) where vague tonal lineaments in Holocene alluvium and a possible trough (erosional?) suggest recent faulting.

Aberdeen Road Section

The Aberdeen Road section of the southern White Mountains fault zone is generally well-defined and is delineated by well-defined, youthful scarps in late Pleistocene and Holocene alluvial fans (localities 11-13, Figure 3). Mapping by dePolo was generally verified by this writer south of locality 5 (Figure 2).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1985).

Zone for special studies well-defined traces of the southern White Mountains fault zone mapped by Nelson (1966), dePolo (written communication, August 1988), and Bryant (this report) as depicted in Figures 2 and 3 (highlighted in yellow). Principal references cited should be Nelson (1966), dePolo (written communication, August 1988), and Bryant (this report).

The short fault that extends out of the FER study area onto the NE 1/4 of the Big Pine 15-minute quadrangle (Figure 3) is sufficiently active and well-defined and should be zoned. However, the NE 1/4 of the Big Pine 15-minute quadrangle will not be reevaluated at this time, but should be in the future as time permits.

FER reviewed; recommendations approved. Earl W. Hart CEG 935 11/23/88

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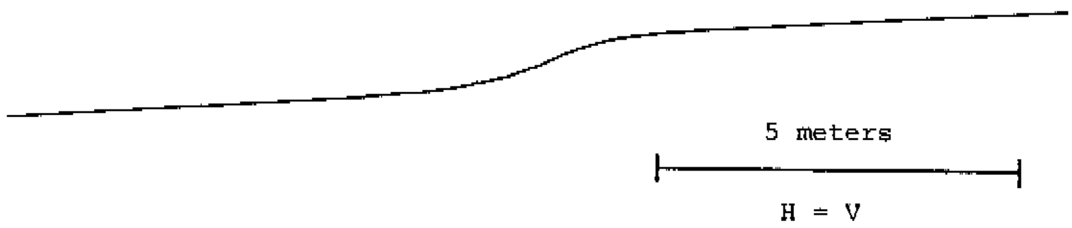
TABLE 1-MORPHOLOGIC DATING OF SELECTED SCARPS

(after Nash, 1987)

Profile WM01 (locality 8, Figure 3)

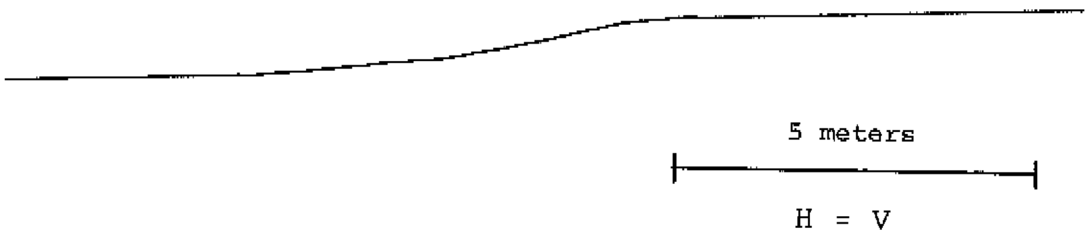


height = 0.85 m
$\measuredangle$ = 23°
crest = 1 m
scarp offset = 0.6 m

tc = 0.175 m^2

assume c[1] = 0.001 m^2/yr
t[2] = 175 yr

Profile WM02 (locality 13, Figure 3)



height = 0.9 m
$\measuredangle$ = 12°
crest = 1 m
scarp offset = 0.7 m

tc = 0.93 m^2

assume c[1] = 0.001 m^2/yr
t[2] = 930 yr

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[1] rate of erosional degradation (diffusivity constant)
[2] time of degradation of original configuration of scarp

Photo 1 (to FER-201). View southeast of scarps (arrows) in Holocene alluvial fan that delineate a branch of the Waucoba Embayment section of the southern White Mountains fault zone (refer to locality 1, Figure 3 for location of photo).